Description of Model Tests Carried Out by Aalborg University

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FULL-SCALE LOAD MONITORING OF RUBBLE MOUND BREAKWATERS.

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Description of model tests carried out by Aalborg University.

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1.1 Introduction

As associated partner, Aalborg University (AU) have participated in different aspects of "the Zeebrugge project". AU has carried out an extensive number of small-scale model tests (1:65) with the Zeebrugge breakwater with the aim of investigating scale-effects. The paragraphs below render concisely the work carried out by AU.

1.2 Physical model tests 1:65

AU has been involved with the execution of extensive physical model testing with the Zeebrugge breakwater. Conducting tests at a third scale 1:65 besides 1:20 and 1:30 makes it possible along with the prototype measurements to evaluate scale effects. In order to do this it is imperative to test models which are alike except for the scale and furthermore, to carry out identical test programmes. At the point in time when AU was to start testing, two different test strategies had already been applied at UCC and HRLB respectively. Where UCC had constructed a model with distorted scaling of the core material HRLB had applied strict Froude scaling. Therefore, it was decided at AU to do tests with both types of models and furthermore, conduct tests on a third model with a third scaling of the core material thus permitting an evaluation of how to scale the core material in order to achieve a hydraulic response within the breakwater complying with the behaviour of the prototype.

The following paragraphs describes the model setup. Where nothing else is stated geometries and soforth is valid for all three models as the only difference is the applied core material.

1.2.1 Model setup

AU have both different flumes and basins available. It was decided to perform the tests in a shallow water bassin. Besides of the availability at that point in time the decision was made in order to avoid using efforts on applying active wave absorption. Also it can be expected that larger setup occurs in the flume and long periodic waves are more predominant.

Model and wave generator was placed in the bassin with weakly reflecting rubble slopes at the edges. This placement is illustrated on figure 1.

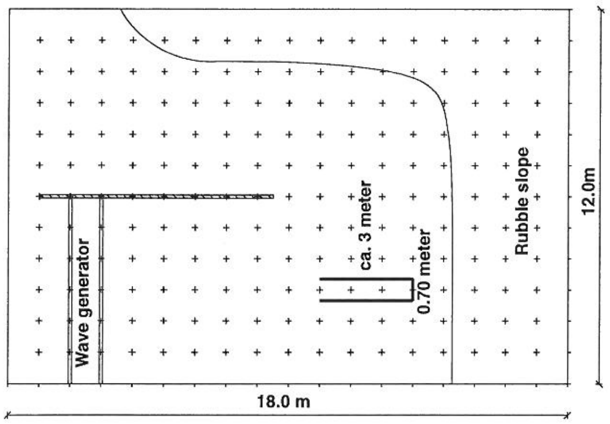

Figure 1: *Placement of model in wave bassin.*

Small-scale antifer cubes	
Mean density: $\rho_m = 2341.57\frac{kg}{m^3}$	
Weights	Nominal diameter
$W_{15} = 85.34gr$	$D_{15} = 3.32cm$
$W_{50} = 86.86gr$	$D_{50} = 3.34cm$
$W_{85} = 88.33gr$	$D_{85} = 3.35cm$
$W_{mean} = 86.02gr$	$D_{\frac{15}{85}} = 0.9886$

Table 1: *Model antifer cubes.*

1.2.2 Model description

The objective was to conduct small-scale tests and as Flanders Hydraulics Laboratory (HRLB) was able to provide small-scale antifer blocks, these were used. One hundred blocks were weighed and the density determined resulting in the data shown in table 1.

Applying the formula taking into account the use of fresh water in the laboratory facility the scale of the model antifers can be deduced as

$$\lambda = \left(\frac{W_n}{W_m \; 1.03}\right)^{\frac{1}{3}}$$

where W_n is the weight of the antifers in prototype and W_m in model. This results in a scale of $\lambda = 65.377$.

Characteristics of the geometry and materials in prototype has been reported in previous full-progress reports. These informations were used to determine scaled values for the first AU model which was strictly Froude scaled. The material characteristics for this model is seen in table 2.

Material	D_{15}	D_{50}	D_{85}	W_{50}	ρ
Core	0.18 cm	0.40 cm	0.59 cm	0.12 gr	$2.65t/m^3$
Filter	1.43 cm	1.64 cm	1.74 cm	8.18 gr	do.
Toe	1.66 cm	1.80 cm	1.95 cm	10.8 gr	do.
Armour	-	3.76 cm	-	86.9 gr	$2.34t/m^3$
Seagravel	-	0.19 mm	0.53 mm	0.013 gr	$2.65t/m^3$
Seasand	-	0.0031 mm	-	-	do.
Willow 1	-	-	-	$37gr/dm^3$	do.
Willow 2	-	-	-	$111gr/dm^3$	do.

Table 2: *Froude scaled materials.*

The model was constructed according to Froude scaling without modelling the seabed topography in front of the breakwater. A page below holds a plot of the breakwater. Backfilling and seabed were closed of from the rest of the model by the use of plastic sheets as the seasand could not be scaled to the required very small grain size (0.0031 mm). As willow mattresses a geotextile was applied performing the protective task of the willow mattresses in prototype. The core of the model was infiltrated with sand to the level recorded in prototype.

Two additional models were constructed at AU and subsequently tested. The second with the core material scaled as $\lambda = 20$ and the third using the scale $\lambda = 40$. The distorted scaling of the second model was determined using the method of Le Mehaute as done at UCC (see full progress report 1994). This results in a scaling of the core material af $\lambda = 16$ till $\lambda = 24$ depending on the incident wave heights. A scale of 1:20 was applied due to the availability of such a material.

Third scaling of the core was decided on the basis of the hydraulic response of the latter two models, with the aim of matching the prototype.

1.2.3 Instrumentation

Instrumentation consisted of three wave gauges a run-up gauge and twelve pressure sensors. Wave gauges was placed relative to the breakwater axis as shown on figure 2.

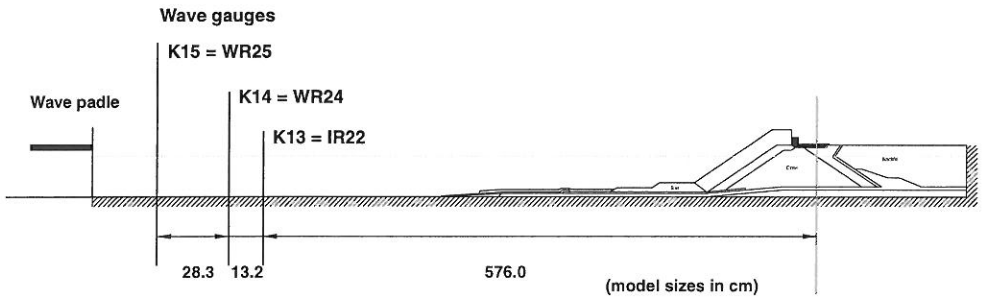

Figure 2: *Location of wave gauges relative to breakwater axis.*

The run-up gauge was, like the wave gauges, a resistance type gauge and this was placed on the face of the breakwater.

Twelve rigid tubes with a perforated cross-beam was placed inside the breakwater core according to the locations of pressure sensors in the prototype as they were 1/1-95. Outside the model, the pressure sensors were fitted to the end of the tubes carefully ensuring that no trapped air was contained in the system. The pressure measurement system have earlier been used at AU and its usability verified. In figure 3 an illustration of the system is seen.

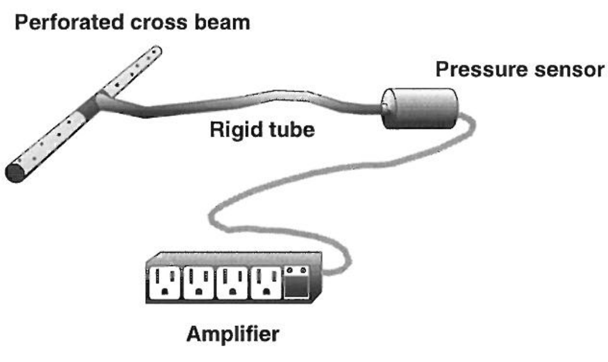

Figure 3: *Illustation of pressure measurement system.*

1.2.4 Conduction of tests

Tests with irregular waves was carried out using a Pierson-Moskowitz spectrum and filtering of white noise was used as generation method.

Sensor signals were sampled in all tests using a sampling frequency of $f = 10hz$. This results in signal descriptions with clearly sufficient resolution.

Test results are available as one file pr. test or one file pr. channel for each test. The structure of the database enables the use of the MAST-software developed by Elis. Scaling in this system is though limited applicable sample frequencies in prototype being restricted to integers. Specialised software for the analysis of the model test data from AU has been developed.

The conducted tests programme consists of a number of tests with both regular and irregular waves. Table 3 shows the test programme applied for all three sets of model tests at AU where values are expressed in prototype magnitudes.

As seen tests have been carried out at four different water levels and it should therefore be noticed that some sensors will be out of the water during a number of the tests. The duration of each test lasted 9000 data points corresponding to fifteen minutes in model scale.

2.1 Test programme

Please refer to paragraph 1.2.4.

2.2 Available results

Results are available from three small-scale models constructed at AU. Data have been collected during an extensive test programme resulting in more than thirteen million numbers. These results of course cannot be rendered here. Due to the vast amount of data, AU has used the analysis strategy not analysing all time series, but selecting relevant data for specific desired analyses.

Irregular waves

$H_s m$	$Z = +4.62m$	$Z = +2.47m$	$Z = +5.92m$	$Z = +0.32m$
1.0		X		X
1.5	X		X	
2.0	X	X	X	X
2.5	X			
3.0	X	X	X	X
3.5	X			
4.0	X	X	X	
4.5	X			
5.0	X			

Regular waves

Hm	$T = 5.0s$	$T = 6.0s$	$T = 7.0s$	$T = 8.0s$	$T = 9.0s$
3.0	X	X	X	X	X
4.0	X	X	X	X	X

Table 3: *Test programme.*

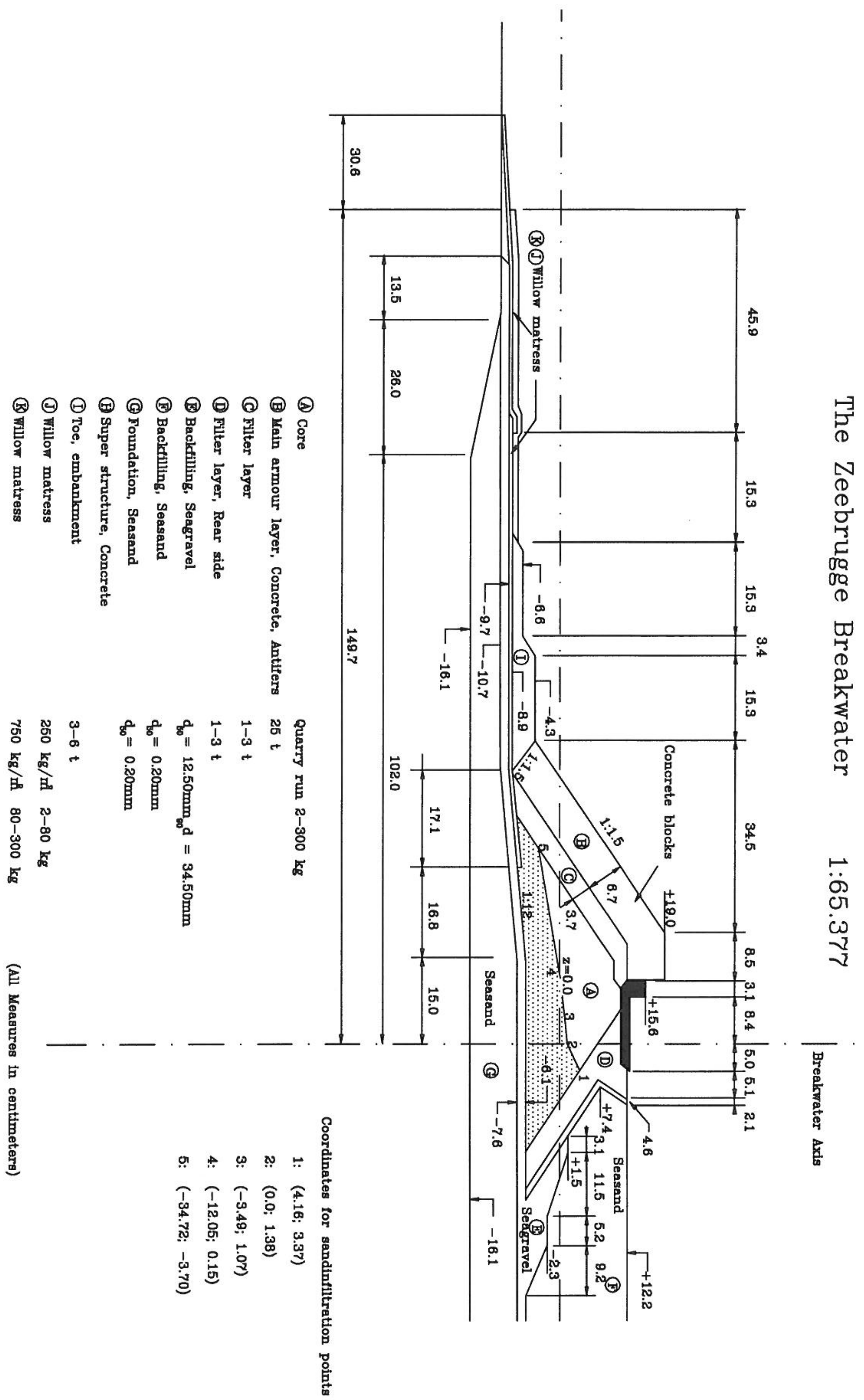

Figure 4: *Plot of model geometry.*

2.3 Information regarding data-package

1) How to restore the data:

   [a)] Copy the file named "arj.exe" from the last disk to your harddisk.

   [b)] Write the command: $arj\ x\ -v\ -y\ \ a:\backslash AUdata.a01$

   NB! The data takes up about 60 MB of space uncompressed.

2) The nature of the data:

   Each file $K01 \longrightarrow K16$ contains one channel. The files (or channels) corresponds to prototype as follows:

Channel translation:	x[m]	z[m]
$K01 \longrightarrow PR10$	-0.1869	0.0458
$K02 \longrightarrow PR11$	-0.2790	0.0107
$K03 \longrightarrow PR12$	-0.1932	0.0459
$K04 \longrightarrow PR13$	-0.1219	0.0104
$K05 \longrightarrow PR14$	-0.2190	0.0107
$K06 \longrightarrow PR16$	-0.1869	0.0106
$K07 \longrightarrow PR17$	-0.1219	0.0456
$K08 \longrightarrow PR18$	-0.1219	0.0349
$K09 \longrightarrow PR19$	-0.1869	0.0351
$K10 \longrightarrow PR21$	-0.2412	0.0352
$K11 \longrightarrow PR26$	-0.2011	0.0352
$K12 \longrightarrow PR27$	-0.0341	0.0363
$K13 \longrightarrow IR22$	-5.7600	0.0000
$K14 \longrightarrow WR24$	-5.8920	0.0000
$K15 \longrightarrow WR25$	-6.1750	0.0000
$K16 \longrightarrow RU28$	-	-

   The data are stored in "ASCII-integers" for the MAST-software. If you apply a scaling factor of 0.0005 you will obtain data in model scale. If you apply $0.0005 \cdot 65.377 = 0.03269$ you will obtain "prototype-sized" data. We have some problems using prototype sizes in the MAST-software as the sample frequency is 10 Hz in the model equal to $\frac{10Hz}{\sqrt{65.377}} = 1.24Hz$ in prototype. The MAST-software only deals with integers as sample frequencies.

   The directory named *Froude* contains tests with Froude scaling of the core material whereas the directory *Reynolds* contains tests with distorted scaling of the core material of 1:20 and finally, the directory *Reynold2* contains tests with distorted scaling of the core material of 1:40.

List of files (Wave heights and periods in prototype):

Directory	Waves	Waterdepth (in bassin)	H_{target}	T_{target}
H10T05Z0	PM	$11.2cm \rightarrow 7.32m$	1.0 m	5.00 s
H20T07Z0	do.	do.	2.0 m	7.07 s
H30T09Z0	do.	do.	3.0 m	8.69 s
H10T05Z2	PM	$14.5cm \rightarrow 9.48m$	1.0 m	5.00 s
H20T07Z2	do.	do.	2.0 m	7.07 s
H30T09Z2	do.	do.	3.0 m	8.69 s
H40T10Z2	do.	do.	4.0 m	10.0 s
H15T06Z4	PM	$17.8cm \rightarrow 11.64m$	1.5 m	6.13 s
H20T07Z4	do.	do.	2.0 m	7.07 s
H25T08Z4	do.	do.	2.5 m	7.89 s
H30T09Z4	do.	do.	3.0 m	8.69 s
H35T09Z4	do.	do.	3.5 m	9.35 s
H40T10Z4	do.	do.	4.0 m	10.0 s
H45T11Z4	do.	do.	4.5 m	10.6 s
H50T11Z4	do.	do.	5.0 m	11.2 s
H30T05RE	Regular	do.	3.0 m	5.0 s
H30T06RE	do.	do.	3.0 m	6.0 s
H30T07RE	do.	do.	3.0 m	7.0 s
H30T08RE	do.	do.	3.0 m	8.0 s
H30T09RE	do.	do.	3.0 m	9.0 s
H40T05RE	do.	do.	4.0 m	5.0 s
H40T06RE	do.	do.	4.0 m	6.0 s
H40T07RE	do.	do.	4.0 m	7.0 s
H40T08RE	do.	do.	4.0 m	8.0 s
H40T09RE	do.	do.	4.0 m	9.0 s
H02T062	PM	$19.8cm \rightarrow 12.94m$	- m	- s
H10T050	do.	do.	1.0 m	5.00 s
H15T061	do.	do.	1.5 m	6.13 s
H20T071	do.	do.	2.0 m	7.07 s
H30T087	do.	do.	3.0 m	8.69 s
H40T100	do.	do.	4.0 m	10.0 s
H50T112	do.	do.	5.0 m	11.2 s

(change of run-up gauge after this serie)

Tests with distorted scaling of core material 1:20:

R10T50Z0	PM	$11.2cm \rightarrow 7.32m$	1.0 m	5.00 s
R20T71Z0	do.	do.	2.0 m	7.07 s
R30T87Z0	do.	do.	3.0 m	8.69 s

R10T50Z2	PM	$14.5cm \rightarrow 9.48m$	1.0 m	5.00 s
R20T71Z2	do.	do.	2.0 m	7.07 s
R30T87Z2	do.	do.	3.0 m	8.69 s
R40T10Z2	do.	do.	4.0 m	10.0 s
R15T61Z4	PM	$17.8cm \rightarrow 11.64m$	1.5 m	6.13 s
R20T71Z4	do.	do.	2.0 m	7.07 s
R25T79Z4	do.	do.	2.5 m	7.89 s
R30T87Z4	do.	do.	3.0 m	8.69 s
R35T94Z4	do.	do.	3.5 m	9.35 s
R40T10Z4	do.	do.	4.0 m	10.0 s
R45T11Z4	do.	do.	4.5 m	10.6 s
R50T11Z4	do.	do.	5.0 m	11.2 s
R30T50RE	Regular	do.	3.0 m	5.0 s
R30T60RE	do.	do.	3.0 m	6.0 s
R30T70RE	do.	do.	3.0 m	7.0 s
R30T80RE	do.	do.	3.0 m	8.0 s
R30T90RE	do.	do.	3.0 m	9.0 s
R40T50RE	do.	do.	4.0 m	5.0 s
R40T60RE	do.	do.	4.0 m	6.0 s
R40T70RE	do.	do.	4.0 m	7.0 s
R40T80RE	do.	do.	4.0 m	8.0 s
R40T90RE	do.	do.	4.0 m	9.0 s
R15T61Z6	do.	$19.8cm \rightarrow 12.94m$	1.5 m	6.13 s
R20T71Z6	do.	do.	2.0 m	7.07 s
R30T87Z6	do.	do.	3.0 m	8.69 s
R40T10Z6	do.	do.	4.0 m	10.0 s
R50T11Z6	do.	do.	5.0 m	11.2 s

Tests with distorted scaling of core material 1:40:

M10T50Z0	PM	$11.2cm \rightarrow 7.32m$	1.0 m	5.00 s
M20T71Z0	do.	do.	2.0 m	7.07 s
M30T87Z0	do.	do.	3.0 m	8.69 s
M10T50Z2	PM	$14.5cm \rightarrow 9.48m$	1.0 m	5.00 s
M20T71Z2	do.	do.	2.0 m	7.07 s
M30T87Z2	do.	do.	3.0 m	8.69 s
M40T10Z2	do.	do.	4.0 m	10.0 s
M15T61Z4	PM	$17.8cm \rightarrow 11.64m$	1.5 m	6.13 s
M20T71Z4	do.	do.	2.0 m	7.07 s
M25T79Z4	do.	do.	2.5 m	7.89 s
M30T87Z4	do.	do.	3.0 m	8.69 s
M35T94Z4	do.	do.	3.5 m	9.35 s
M40T10Z4	do.	do.	4.0 m	10.0 s
M45T11Z4	do.	do.	4.5 m	10.6 s
M50T11Z4	do.	do.	5.0 m	11.2 s
M30T50RE	Regular	do.	3.0 m	5.0 s

M30T60RE	do.	do.	3.0 m	6.0 s
M30T70RE	do.	do.	3.0 m	7.0 s
M30T80RE	do.	do.	3.0 m	8.0 s
M30T90RE	do.	do.	3.0 m	9.0 s
M40T50RE	do.	do.	4.0 m	5.0 s
M40T60RE	do.	do.	4.0 m	6.0 s
M40T70RE	do.	do.	4.0 m	7.0 s
M40T80RE	do.	do.	4.0 m	8.0 s
M40T90RE	do.	do.	4.0 m	9.0 s
M15T61Z6	do.	$19.8cm \rightarrow 12.94m$	1.5 m	6.13 s
M20T71Z6	do.	do.	2.0 m	7.07 s
M30T87Z6	do.	do.	3.0 m	8.69 s
M40T10Z6	do.	do.	4.0 m	10.0 s
M50T11Z6	do.	do.	5.0 m	11.2 s

Channel K07 and K08 is not working for the second set of tests (starting with R). Wave run-up is not measured correctly until the gauge was changed. Besides these imperfections channels may have failed in some of the tests, but it is easily seen on the data when viewed.